Supersonic X-ray-emitting shocked ISM in Centaurus A

Comprehensive study of Cen A using *Chandra*/XMM-Newton/VLA/ATCA

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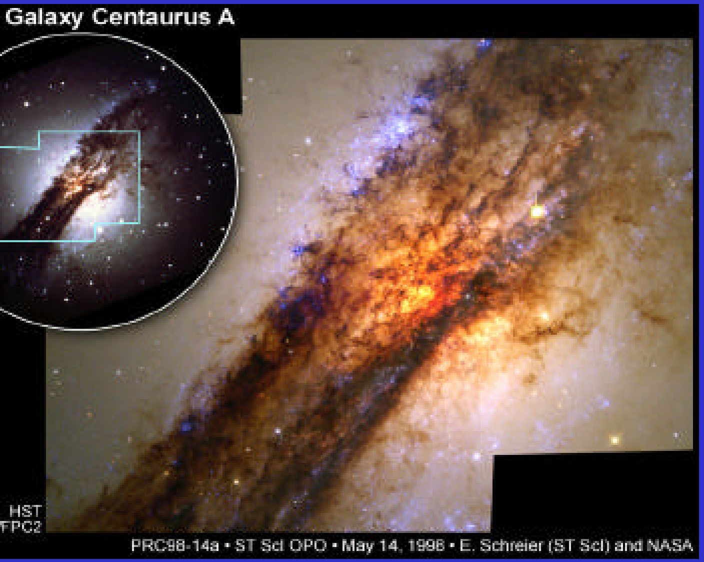
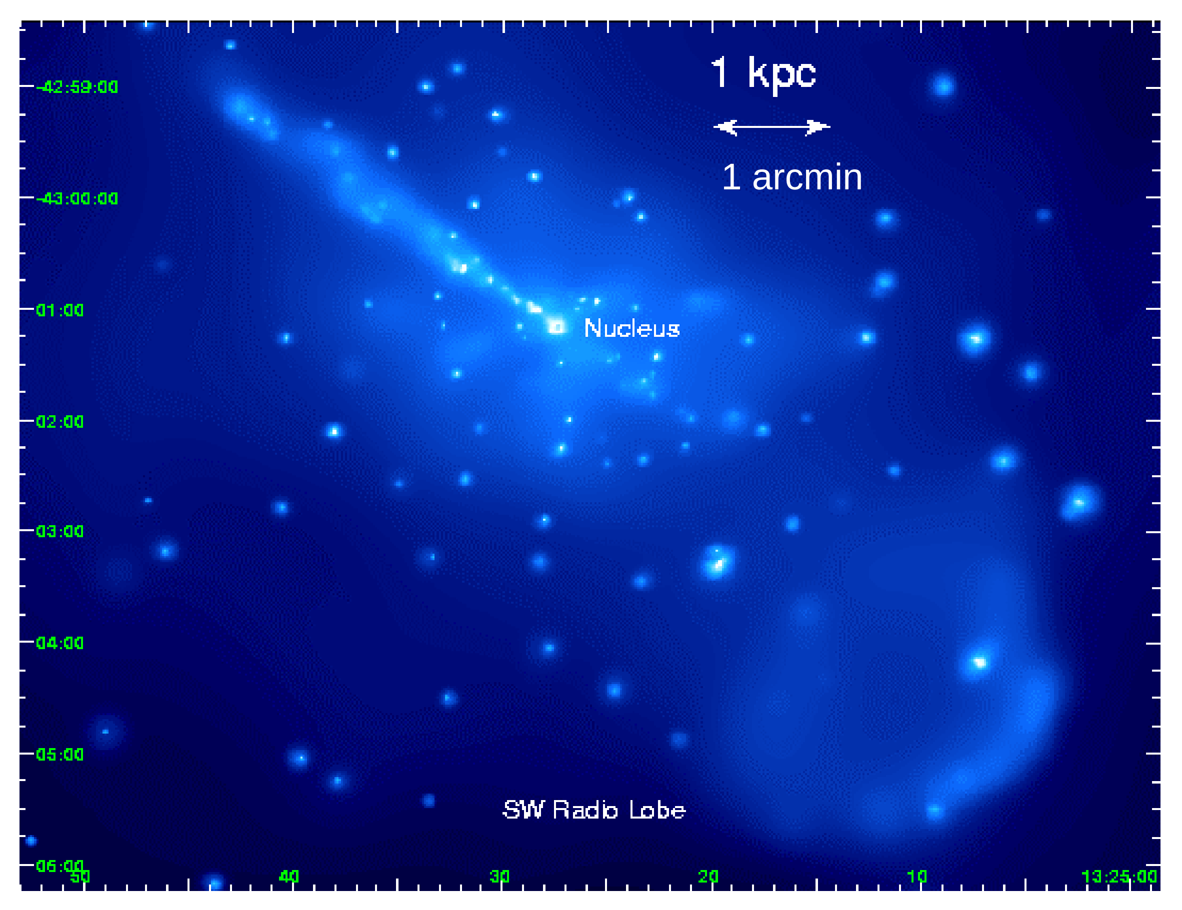
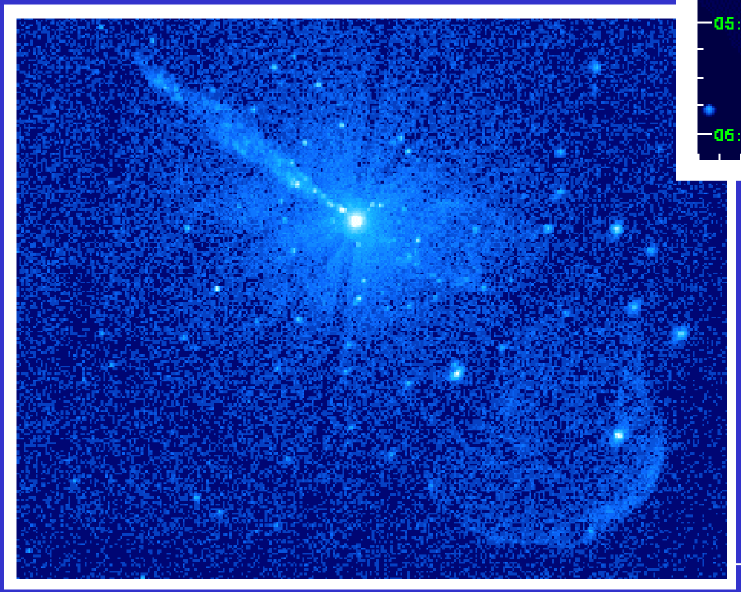
Nearest radio galaxy. D = 3.4 Mpc

NGC 5128

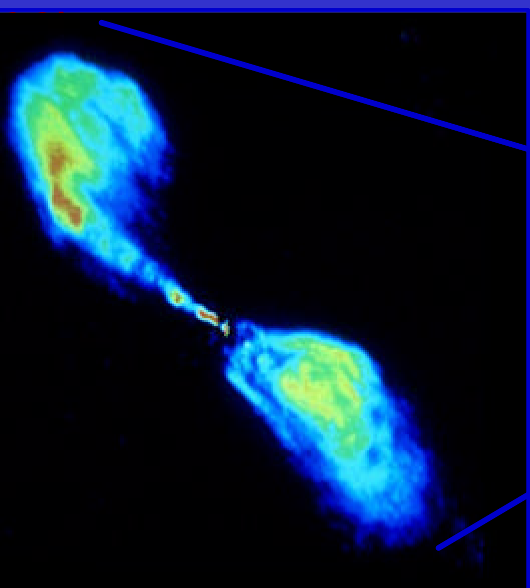




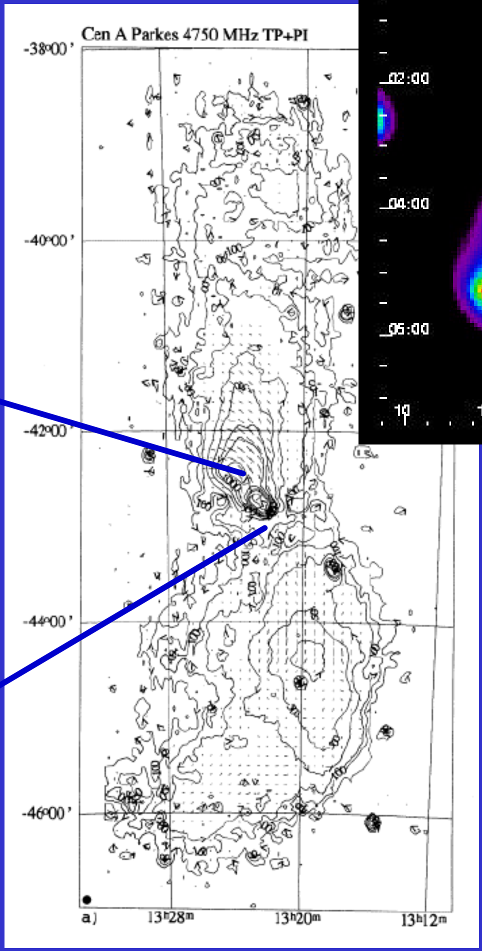


Chandra

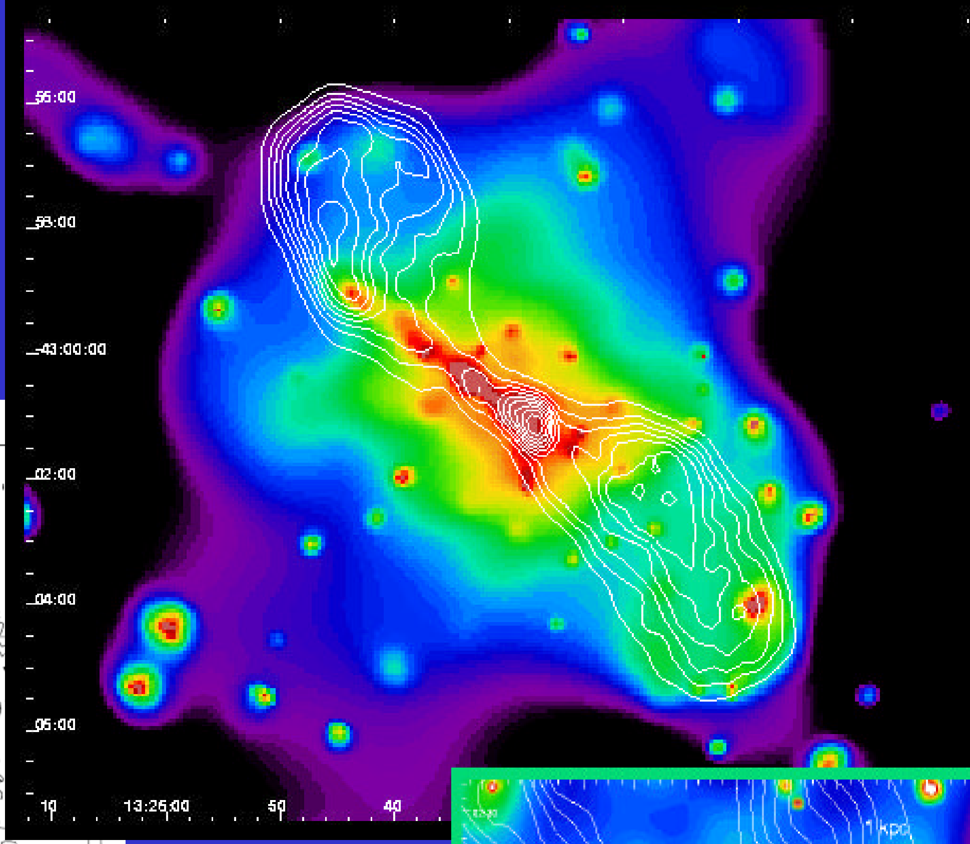
GHz VLA image of
rns et al. (1983) and full
dio extent (Junkes et al.

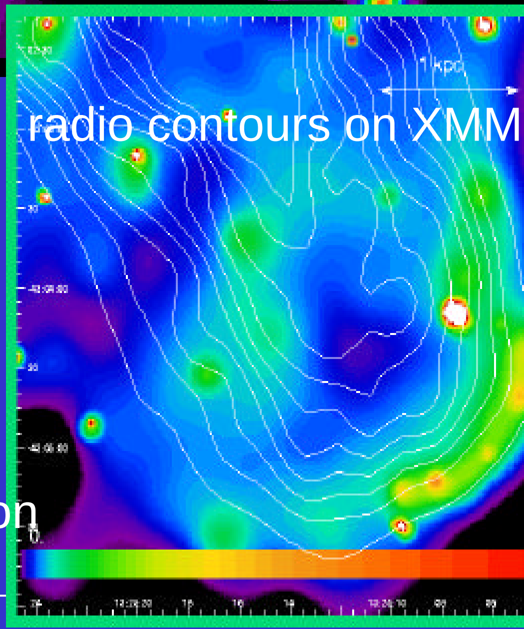


12 kpc



500 kpc





radio
~30''
resolution

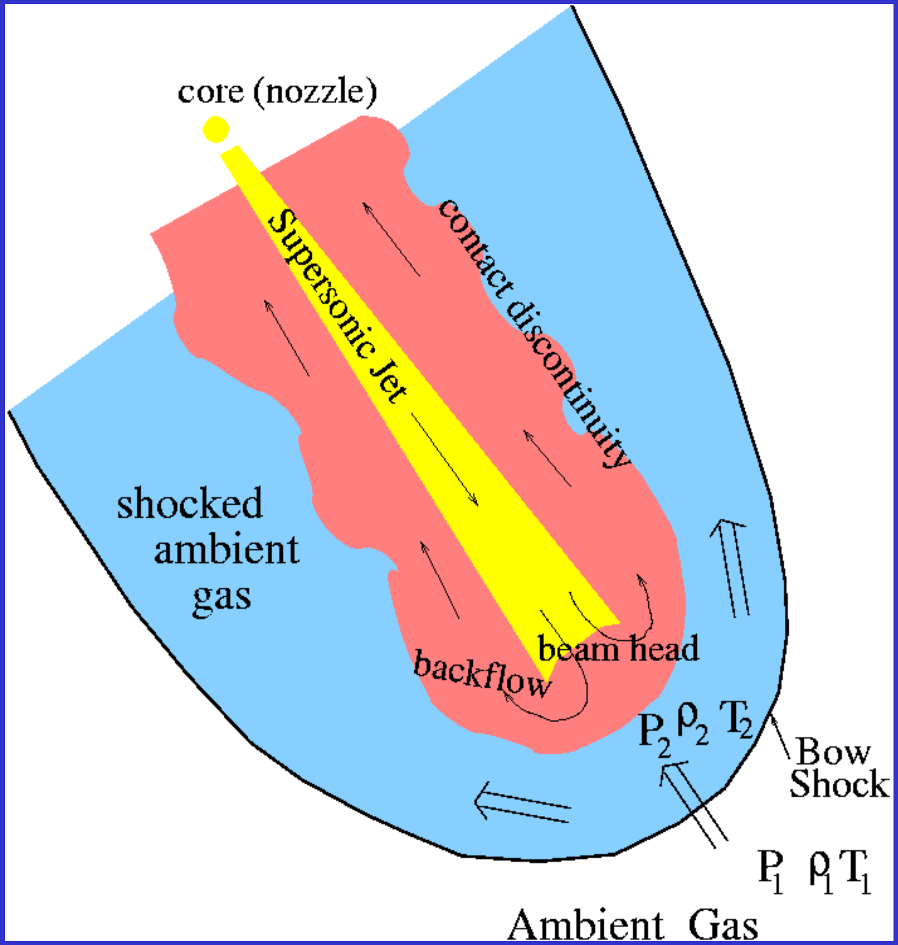
The shock jump conditions at the head of the bow shock are (e.g. Spitzer 1978):

$$P_2/P_1 = (5\mathcal{M}^2 - 1)/4$$
$$\rho_2/\rho_1 = 4\mathcal{M}^2/(\mathcal{M}^2 + 3)$$
$$T_2/T_1 = (5\mathcal{M}^2 - 1)(\mathcal{M}^2 + 3)/16\mathcal{M}^2$$

where $\mathcal{M}$ is the Mach number corresponding to the velocity v_{adv} at which the lobe advances into the external medium, i.e.,

$$\mathcal{M} \sim 580\ (v_{adv}/c)\ (kT_1/keV)^{-1/2}$$

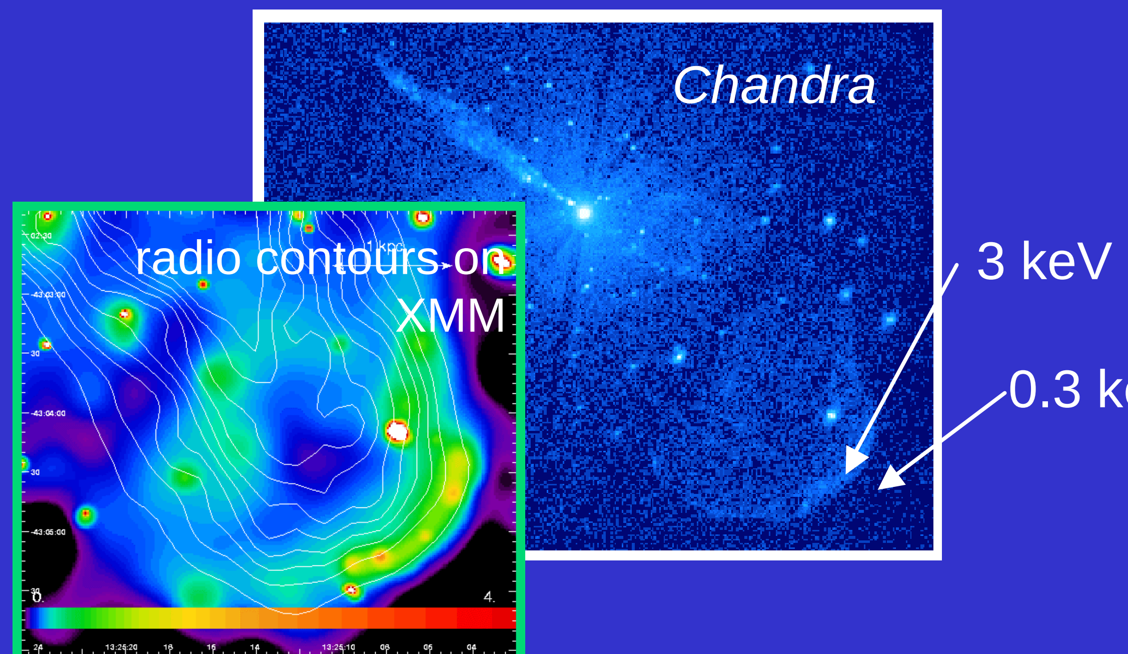
(For v_{adv} >~ 0.02c, heating so large that the emissivity in the Chandra band is less than that of the ambient medium.)



Temperature and density measurements for both the ambient medium and shocked gas directly test shock heating since only three of the four parameters are required to measure the Mach number; the fourth tests the model.

The shell's density and temperature are wrong for gas in contact with the bow shock, but are correct for gas which has adiabatically cooled (e.g. Alexander 2002) in pressure balance with gas of kT_2 ~ 6.8 keV, where v_{adv} ~ 2400 km s^{-1} , $\mathcal{M}$ ~ 8.5.

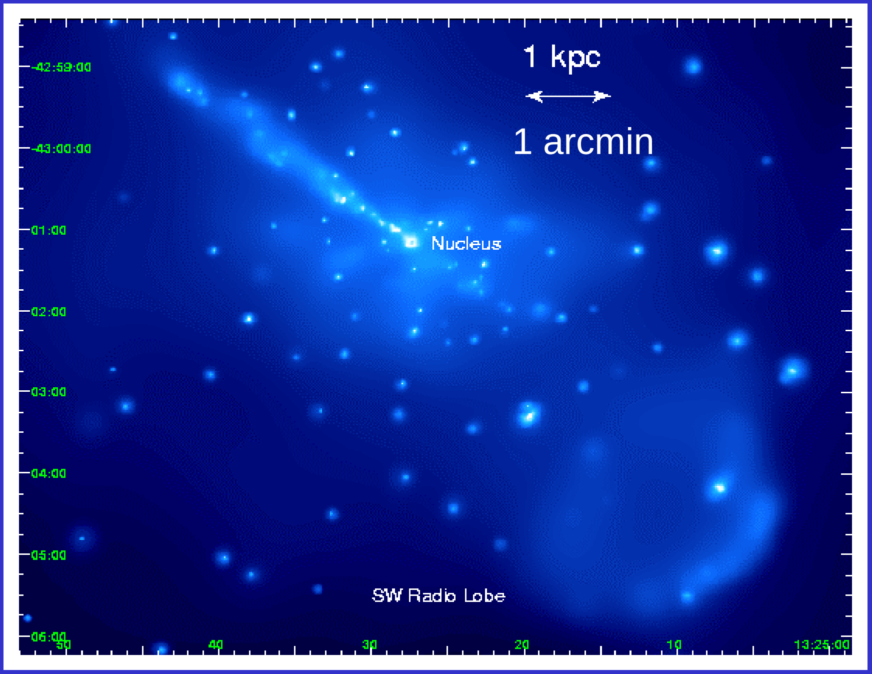
(Emissivity of the 6.8 keV gas too low to separate its X-rays from those of the diffuse ISM.)



Implications for Constellation X

High-throughput spectroscopy could map the gas kinematics. (Speeds < 0.008 c)

But, for Cen A, fov > 2.5 arcmin desirable



Heating detected where not expected (jet powering lobe no longer visible, and must have bee sufficient time since any earlier epoch of lobe expansion for the ISM to have been replenished.)

Broader interest from Cen A result:

The shell's kinetic energy is ~6.5 times its thermal energy, and exceeds the thermal energy of the ISM within 15 kpc of the center of the galaxy. As the shell dissipates, it will have a major effect on Cen A's ISM, providing distributed heating.

The tip of the iceberg:

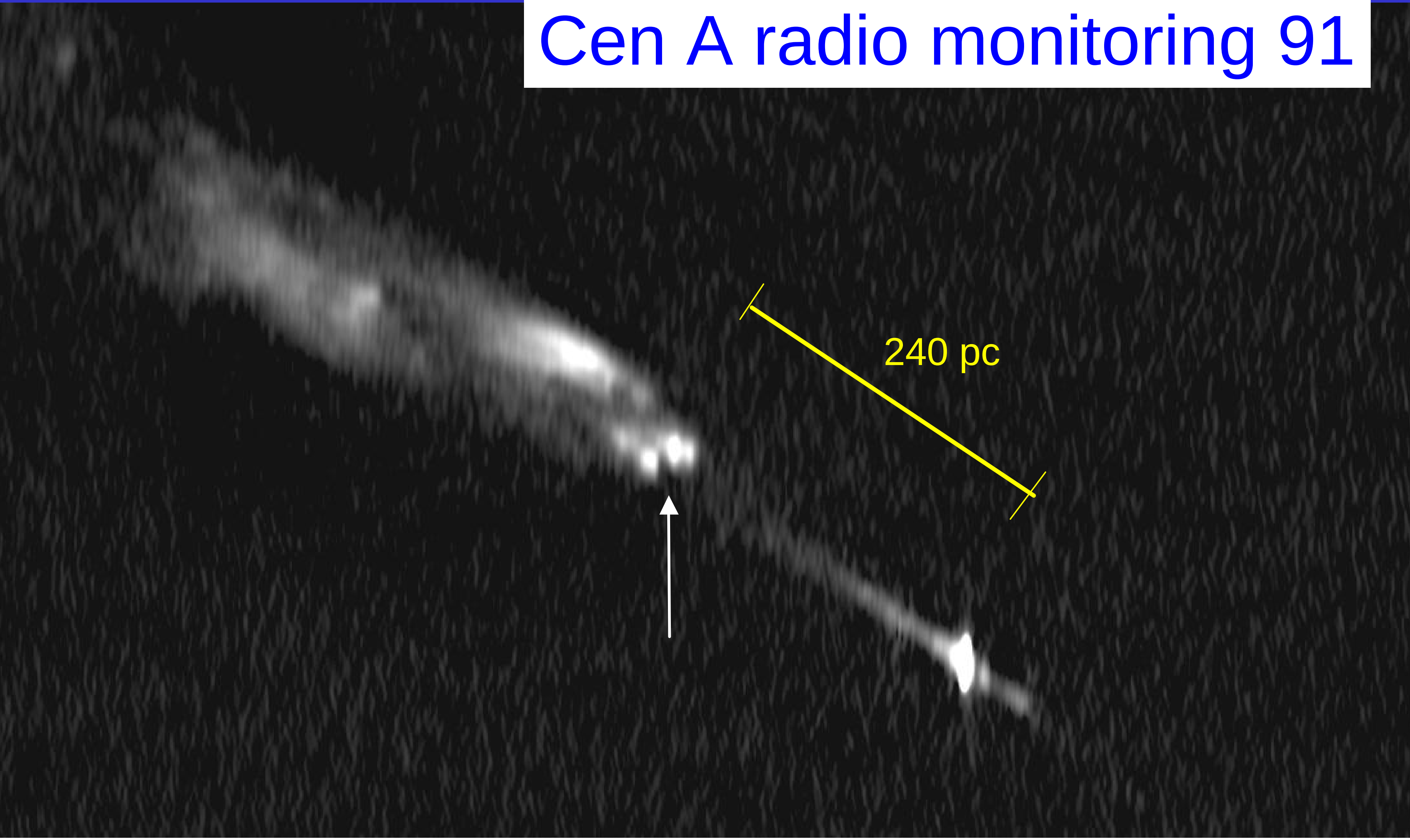
With high throughput, conditions should be correct to detect heated gas and measure the advance speed around radio sources with jets. Combine with

Thrust Equation & Energy Equation

(based on internal energy)

$\rightarrow$ v_{jet}, ρ_{jet}

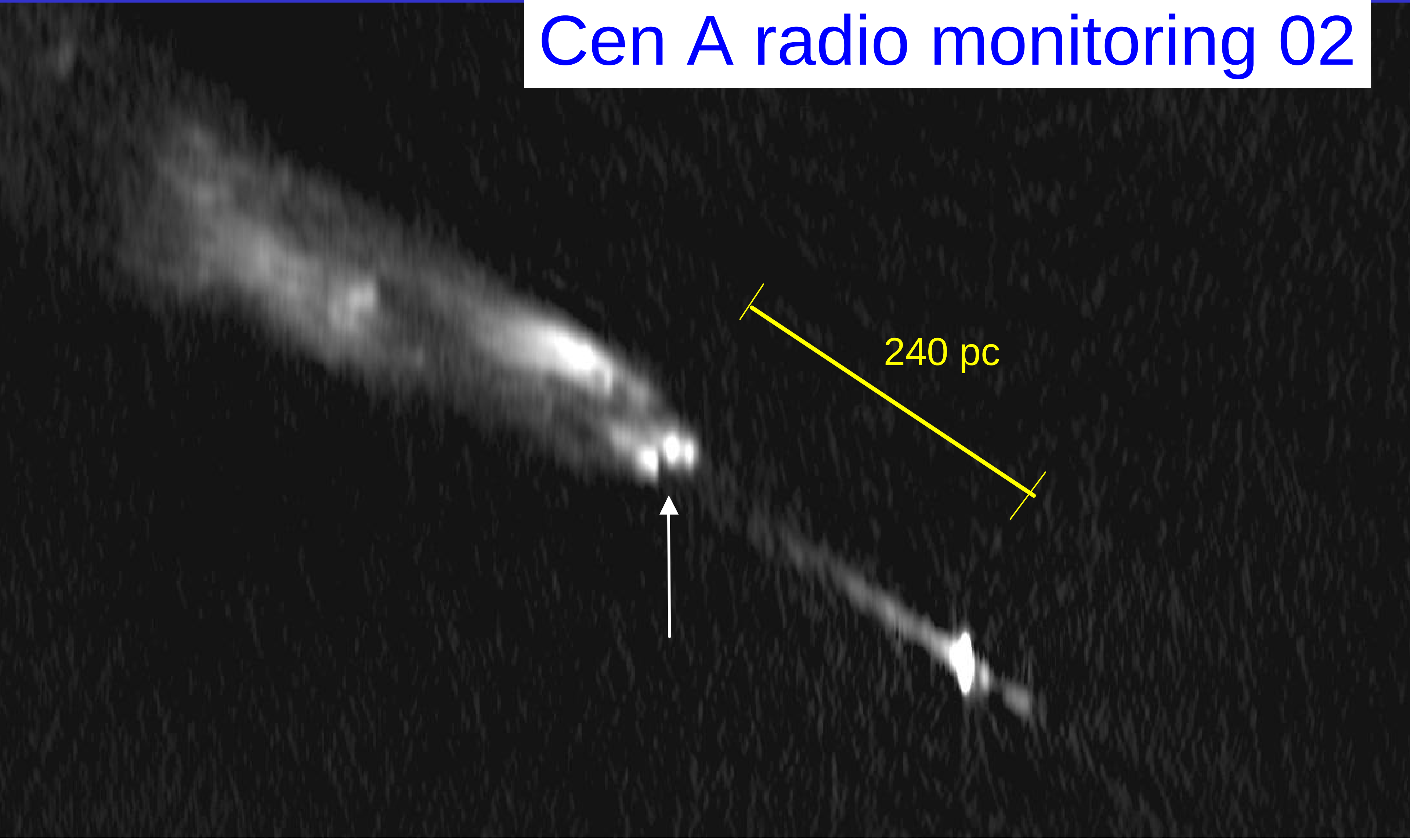
Cen A radio monitoring 91



VLA 8.4 GHz A & B array: 1991 archival, 2002 new. Dynamic range 120,000:1. Proper motions: v_{app} ~ 0.5c. If ? ~ 50°, jets asymmetric.

Hardcastle et al. (2003).

Cen A radio monitoring 02



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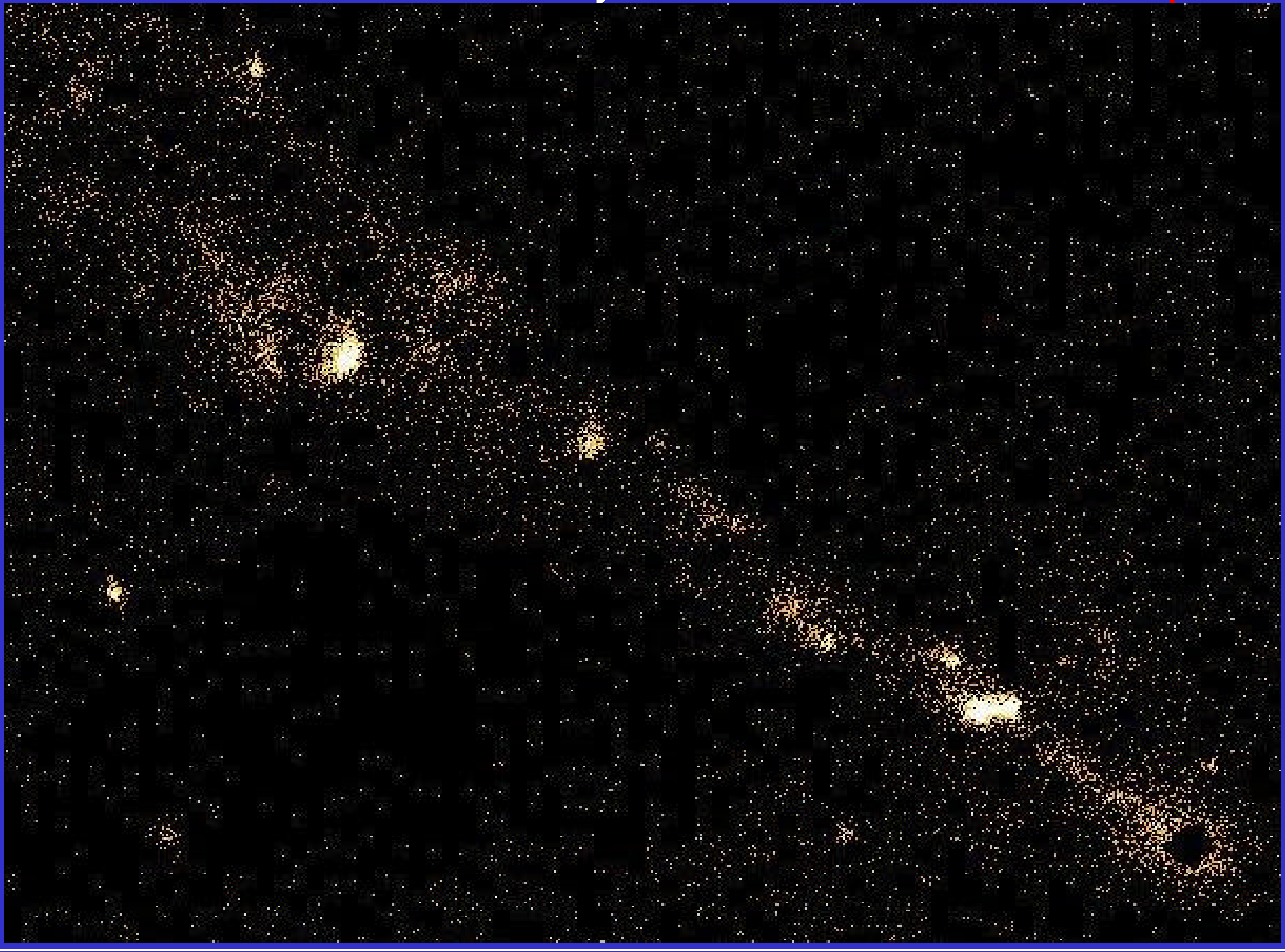
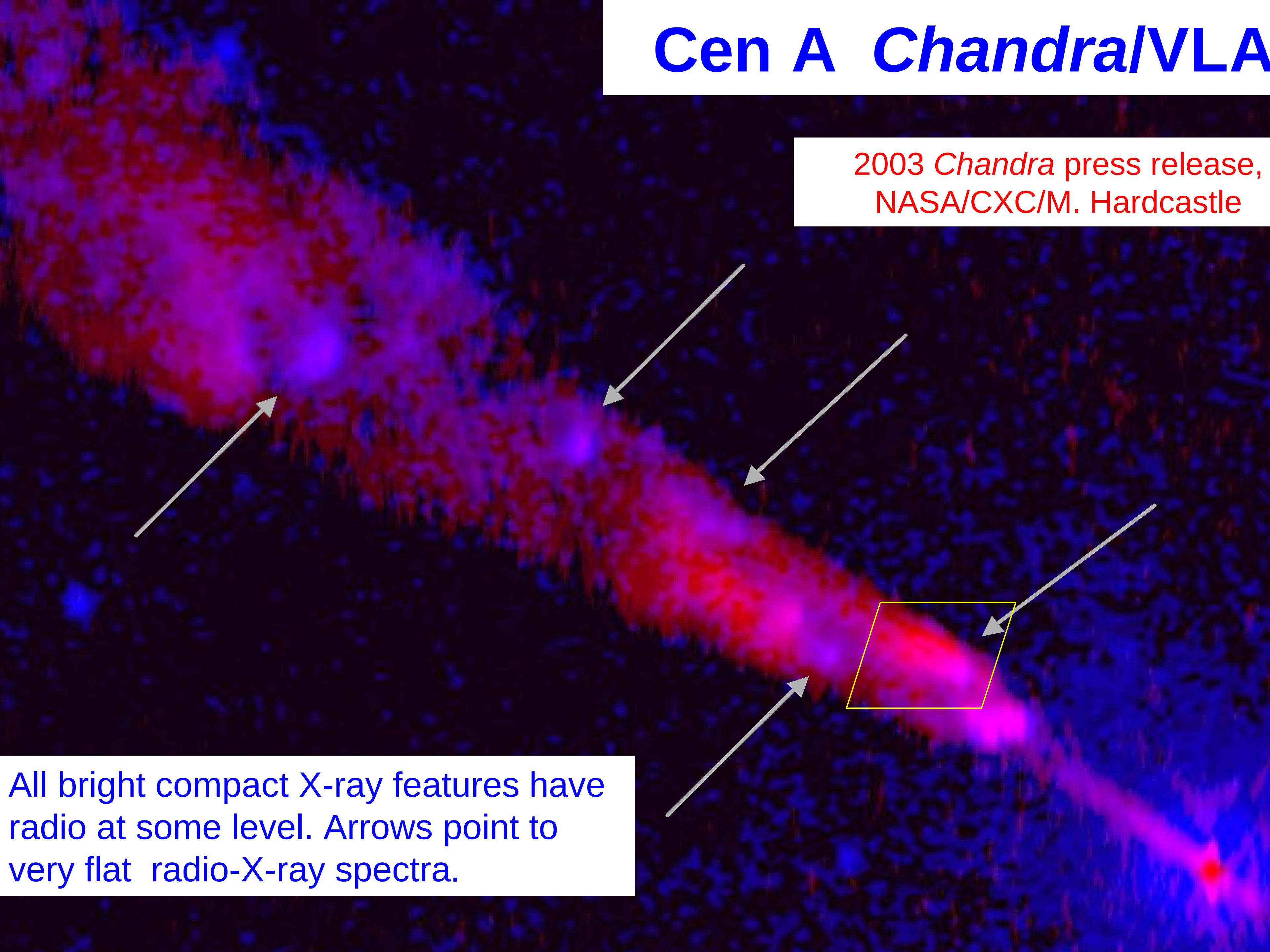
Chandra ACIS-S 45 ks X-ray

Jet and weak counter-jet

Hardcastle et al. (2003)



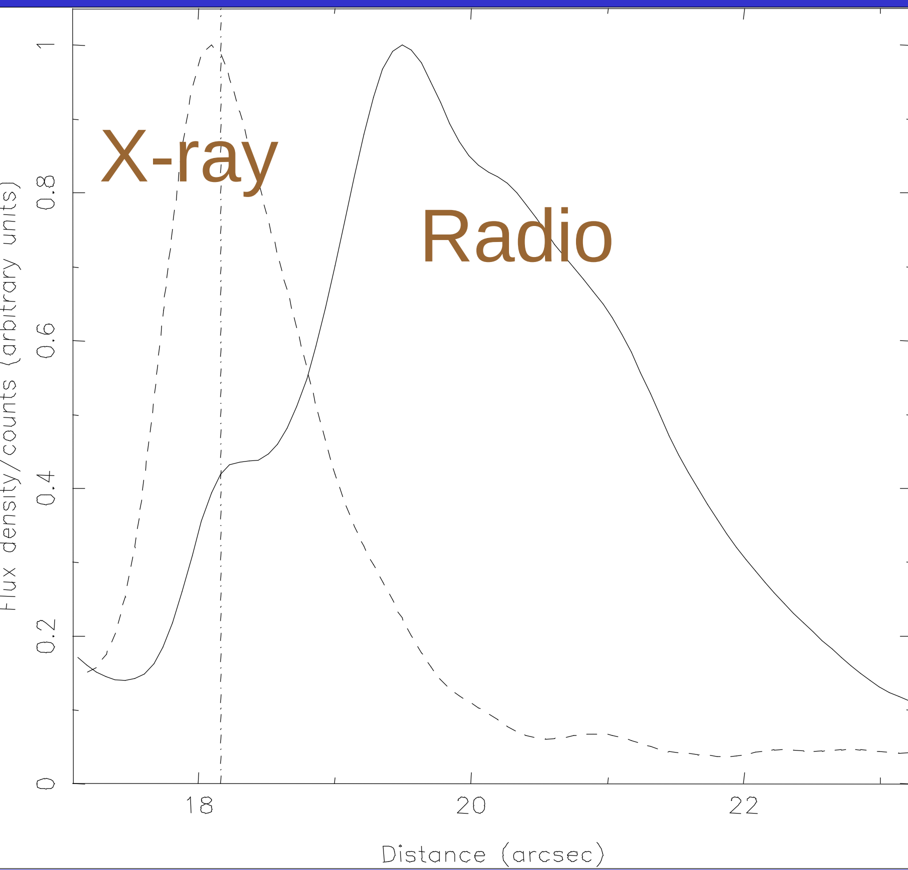
Cen A *Chandra*/VLA



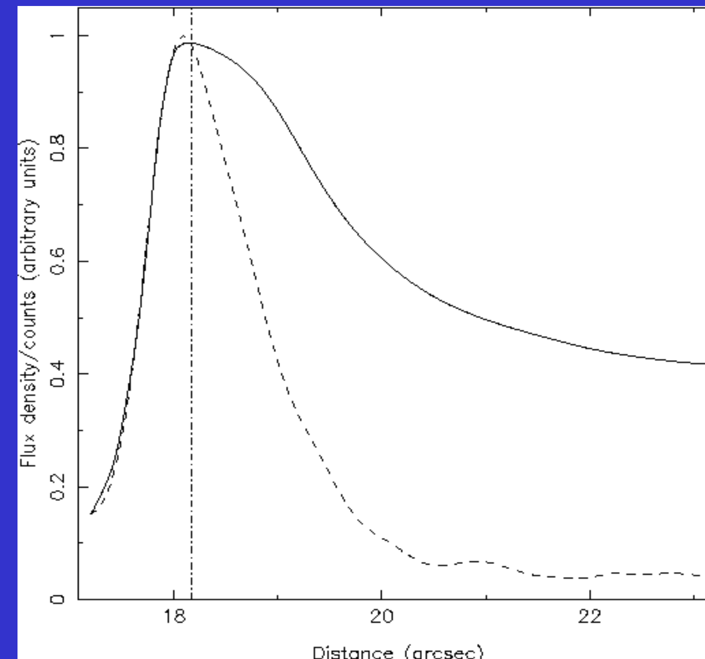
2003 *Chandra* press release,
NASA/CXC/M. Hardcastle

All bright compact X-ray features have radio at some level. Arrows point to very flat radio-X-ray spectra.

Knot profile



Acceleration and advectio (toy profile)



Alternative toy model